COMPARISON OF ABRASIVE WEAR RESISTANCE BETWEEN HVOF THERMALLY SPRAYED ALLOY-BASED AND CERMET COATINGS

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Abstract

HVOF (High Velocity Oxygen Fuel) thermal spraying technology is commonly used for component surface protection against abrasive wear. Alloy-based and cermet coatings meet the demands of high abrasive wear resistance. Wear resistance is in many cases a decisive property for the proper functioning of components. Suitable materials for particular applications are usually selected according to their different hardnesses.

For this reason, the present work is focused on the comparison of abrasive wear resistance and hardness of alloy-based and cermet coatings. The coatings sprayed on to steel substrates were subjected to the abrasive wear test according to modified method ASTM G-65 method (Rubber Wheel/Dry Sand Abrasion Test). Abrasive sand Al₂O₃ with grain size of (212-250) µm was used. CoCrWC (Stellite 6), NiCrBSi, CrC-NiCr, CrC-CoNiCrAlY, WC-Co powders were used to prepare sample sets subjected to the test. It was shown that the abrasive wear resistance is not directly proportional to the hardness. The difference in microstructure between cermet and alloy-based coatings results in different wear mechanisms which plays an essential role in the abrasive wear resistance of a particular coating.

Keywords: HVOF, coating, abrasive wear, wear resistance, ASTM G-65

1. INTRODUCTION

Approximately 50% of industrial applications suffer nowadays from abrasive wear [1]. HVOF (High Velocity Oxygen Fuel) coating technology is commonly used for function surface protection [3]. Cermet coatings are one of the most effective coatings for component surface protection [2]. The coatings discussed in this paper are currently some of the most employed coatings in industrial applications due to their outstanding mechanical properties. The characteristic features of WC-Co-based coatings are high hardness and abrasive wear resistance, but their industrial applications are, limited to a temperature of 480°C [4]. Thermally sprayed Cr₃C₂ - 25%NiCr coatings are used in high temperature applications because of the outstanding corrosion and oxidation resistance of nickel-chrome alloy and the acceptable temperature resistance of chrome carbides up to 900°C [5]. Cr₃C₂ - CoNiCrAlY coating provides component surfaces with excellent erosion and wear resistance up to 1000°C. This coating has better oxidation resistance than Cr₃C₂ – NiCr coating [6]. CoCrWC (Stellite 6) alloys are characterized by excellent hardness and toughness and are usually very corrosion resistant. CoCrWC (Stellite 6) alloys also have very high melting points due to their cobalt and chrome content [7]. The last of the discussed coatings was NiCrBSi-based coating, which is formed by very fine particles of precipitating carbides and borides in a nickel matrix with Cr, Si and Fe additives. This coating is mainly used for abrasive wear and erosion protection; also at elevated temperatures. This coating is classified into the group of so-called self-fluxing alloys, which are usually thermally post-treated after spraying to improve mechanical and physical properties [8].

Abrasive wear resistance of the coatings was evaluated by the modified method of ASTM G-65 Dry Sand/Rubber Wheel Abrasion test. A detailed description of the test can be found in the publication [9]. The
aim of this paper is to compare abrasion wear between cermet and alloy-based coatings and to determine the role of the structure differences between cermet and alloy-based coatings in relation to the wear mechanism.

2. EXPERIMENT

The coated samples were deposited using HVOF (High Velocity Oxygen Fuel) thermal spraying technology TAFA JP-5000 in VZÚ Plzeň s.r.o. Coatings were deposited on steel 11 523 substrate samples with a size of 75x25x5 mm. The average coating thickness was 300μm. Cr₃C₂-25%NiCr, Cr₃C₂-CoNiCrAlY and WC-17%Co powders were chosen for cermet coatings, and CoCrWC (Stellite 6) and NiCrBSi powders for alloy-based coatings.

Coating deposition parameters are included in Table 1.

<table>
<thead>
<tr>
<th>Coating</th>
<th>Technology</th>
<th>Barrel length</th>
<th>Deposition distance</th>
<th>Equivalent ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr₃C₂-25%NiCr</td>
<td>HVOF</td>
<td>102mm</td>
<td>360 mm</td>
<td>1.1</td>
</tr>
<tr>
<td>Cr₃C₂-CoNiCrAlY</td>
<td>HVOF</td>
<td>152mm</td>
<td>420 mm</td>
<td>1.06</td>
</tr>
<tr>
<td>WC-17%Co</td>
<td>HVOF</td>
<td>102mm</td>
<td>380 mm</td>
<td>2.34</td>
</tr>
<tr>
<td>CoCrWC (Stellite 6)</td>
<td>HVOF</td>
<td>152mm</td>
<td>360 mm</td>
<td>0.98</td>
</tr>
<tr>
<td>NiCrBSi</td>
<td>HVOF</td>
<td>120mm</td>
<td>360 mm</td>
<td>0.79</td>
</tr>
</tbody>
</table>

Abrasive wear resistance of the coatings was determined by the modified method in accordance with the norm ASTM G-65. The principle of this method is shown in Fig. 1.

Fig. 1: Diagram of Dry Sand/Rubber Wheel test [11].

This method is suitable for evaluating coating wear resistance. The test is arranged selected to evaluate resistance during three-body surface abrasive loading. The test result is volume loss; possible wear rate of given material in cubic millimetres under specific test conditions determined by the chosen procedure. A brief description of the test is as follows: Abrasive particles of determined hardness and grain size are introduced between the rotary wheel equipped with a rubber rim of defined hardness and the sample pressed to the wheel by a determined force. The primary test result is the weight loss of the examined material which is used to calculate volume loss to enable comparison of materials with different densities. The sample was pressed to the rubber rim wheel with a diameter of 231.89 mm with the defined force of 22N. Circumferential speed of the wheel was 200 rev per minute. White corundum with grain size of 212-250 μm was used as the
abrasive material. The amount of corundum introduced between the sample and the wheel was 440 g/min and the sand moisture did not exceed 0.5% of weight amount. Weight loss was measured using a Sartorius TE214S OCE digital scale with accuracy of 0.0001 g. The test was conducted under the temperature of 22 ± 2°C [10].

Coating section microstructure and surface morphology after the abrasive test were evaluated using SEM microscopy Se, Be and Mix modes.

Microhardness was measured with the Vickers hardness test with a 300g load applied for a duration of 10s. Final value is an average of 7 measurements.

Density was determined by the Archimedes´principle. The density of the coatings was measured by gravimetrical method.

Surface roughness tester SJ-201P was used to measure sample surface roughness after deposition. Three measurements were conducted for each coating and the average value including mean deviation was calculated.

Coating thickness was measured in photos of section microstructure. Measurements were always conducted at five locations and an average value was calculated for each coating.

Coating surface hardness was measured using the Rockwell hardness test. The test is based on the principle of a cone shaped indenter indentation into the coating. Each coating was subjected to the test five times and an average value including mean deviation was calculated.

3. RESULTS AND DISCUSSION

This section summarizes all the measured values. The coatings were subjected to an abrasive wear resistance test and coating resistance against three-body abrasive wear under low loading, which excludes abrasive particle deformation. The relation of volume loss and abrasive track for the coatings is shown in Fig. 2. The wear rate (Wr) of individual coatings was determined from linear regression relation of volume wear and track. The results are summarized in Tab. 2.

Fig. 2 Comparison of abrasive wear rate of coating materials

Fig. 2 shows that the highest abrasive wear resistance was obtained by the WC-17%Co coating; followed by Cr3C2-NiCr and Cr3C2-CoNiCrAlY coatings. The measurements confirmed the presumption that the CoCrWC (Stellite 6) coating would have a lower abrasive wear resistance and the NiCrBSi coating the lowest. These results do not correspond with the usual hardness values of alloy-based coatings. The higher hardness did not always guarantee higher abrasive wear resistance. The basic mechanical properties of the five coatings are shown in Tab. 2. Fig. 3 shows wear rate and hardness HR15N and HV0,3 ratio of all five coatings.
From the graphs in Fig. 3 it is seen that surface hardness HR15N can be used as a wear indicator in the range of the group of cermet coatings. In this group, the expectation that harder coatings have higher wear resistance is valid. On the other hand, with the other two alloy-based coatings, the harder NiCrBSi showed lower wear resistance than CoCrWC (Stellite 6). Moreover, the coatings cannot be compared between groups of material only according to their hardness – while the surface hardness of Cr₃C₂-CoNiCrAlY and NiCrBSi is comparable; the wear rate of the NiCrBSi alloy coating is more than 7 times higher. A similar conclusion can be reached in the case of microhardness measurements. The microhardness measurements suffer from big scatter in comparison with the differences between average values. This means that the microhardness of NiCrBSi is comparable to the CrC-based cermet coatings, but its wear rate is much higher.

The difference between the coating wear behaviors can be explained by the wear mechanism (see Fig. 4). In the case of cermet coatings, the hard particles embedded in the microstructure impede against the grooving and ploughing of the soft matrix and the wear resistance is given mainly by the strength of the carbide-matrix interface. In the case of alloy coatings the ploughing is the main wear mechanism. The coatings microstructures (Fig. 5) show that in the case of WC-Co, the lower amount of matrix and well bonded carbides give the best results in terms of wear resistance. The CrC-based coatings with the same amount of matrix (25%) microstructures differ in the amount of porosity and probably in related carbide-matrix cohesion and intersplat cohesion. The coating with the better microstructure, Cr₃C₂-NiCr also shows better wear resistance. The small hard precipitates can be seen in the microstructure of NiCrBSi coating, but their presence does not have a strengthening effect on the wear rate compared to the CoCrWC (Stellite 6) coating. The hard precipitates are probably too small in comparison with the abrasive particles to have a significant effect on the wear resistance. Apart from hardness, material toughness also plays a role in the process of wear. The higher toughness of CoCrWC (Stellite 6) can be expected based on the measured results.
**Fig. 5** Surface morphology of coatings after wear in the middle of the track a) WC-17%Co, b) Cr₃C₂-CoNiCrAlY, c) Cr₃C₂-NiCr, d) NiCrBSi, e) CoCrWC (Stellite 6), magnification 3000x, SEM (Mix)

**Fig. 6** Microstructure of coating section a) WC-17%Co, b) Cr₃C₂-CoNiCrAlY, c) Cr₃C₂-NiCr, d) NiCrBSi, e) CoCrWC (Stellite 6), magnification 3000x, SEM (Mix)
4. CONCLUSIONS

1.) Based on the expectations, it has been proved that cermet coatings have higher abrasive wear resistance in comparison with alloy-based coatings.

2.) It was discovered that hardness HR15N can be used only as an approximate indicator for cermet coatings to determine abrasive wear resistance of coating. Nevertheless, this value cannot be used in the case of alloy-based coatings. The same conclusion was also made for microhardness HV0.3 as an indicator for determining abrasive wear resistance of coating.

3.) The abrasive wear resistance has proved to be influenced mainly by the wear mechanism. Carbides distributed uniformly in the matrix of cermet coatings impede the wear, and the abrasive wear rate is determined by the carbide-matrix bond strength. The alloy-based coatings do not contain carbide phase and therefore the abrasive wear is higher in comparison with cermet coatings.

4.) It has also been proved in this paper that a higher amount of carbides tightly bonded in a lower amount of matrix provide a coating with outstanding abrasive wear resistance.

ACKNOWLEDGEMENT

This paper was prepared with support from grant No. TA02010486.

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